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RATES OF ROUNDING OF QUARTZ GRANULES AND
NATURE OF SEDIMENTARY MATURITY, SAN PEDRO VALLEY,
COCHISE COUNTY, ARIZONA

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Rates of Rounding of Quartz Granules and Nature of Sedimentary Maturity, San Pedro Valley, Cochise County, Arizona ¹

Philip Seff and Walter Smith ²

INTRODUCTION

The Soil and Water Conservation Research Division of the Agricultural Research Service is conducting research on the hydrologic cycle in the semiarid Southwest, near Tombstone, Ariz. Part of the geologic aspect involves an analysis of the valley-filling sediments of the San Pedro River Valley.

Geologic investigations of the younger gravels have so far been concentrated on deposits originating from the Whetstone and Dragoon Mountains north of Tombstone (Fig. 1), where Pleistocene scouring of the valley and modern arroyo cutting have revealed the most extensive exposures of these units. An initial roundness analysis of quartz grains on the Whetstone Surface has been completed and is summarized in this report. As a result of this abrasion study, several relations and trends have been revealed that may prove useful in further studies of slightly transported alluvial gravels. These relations and trends may prove especially valuable for determining source, direction, and distance of transport and may be found useful where deposits are discontinuous or otherwise uncertain. A synopsis of the geologic history of the younger gravel deposits will be helpful prior to a description of the abrasion study in detail.

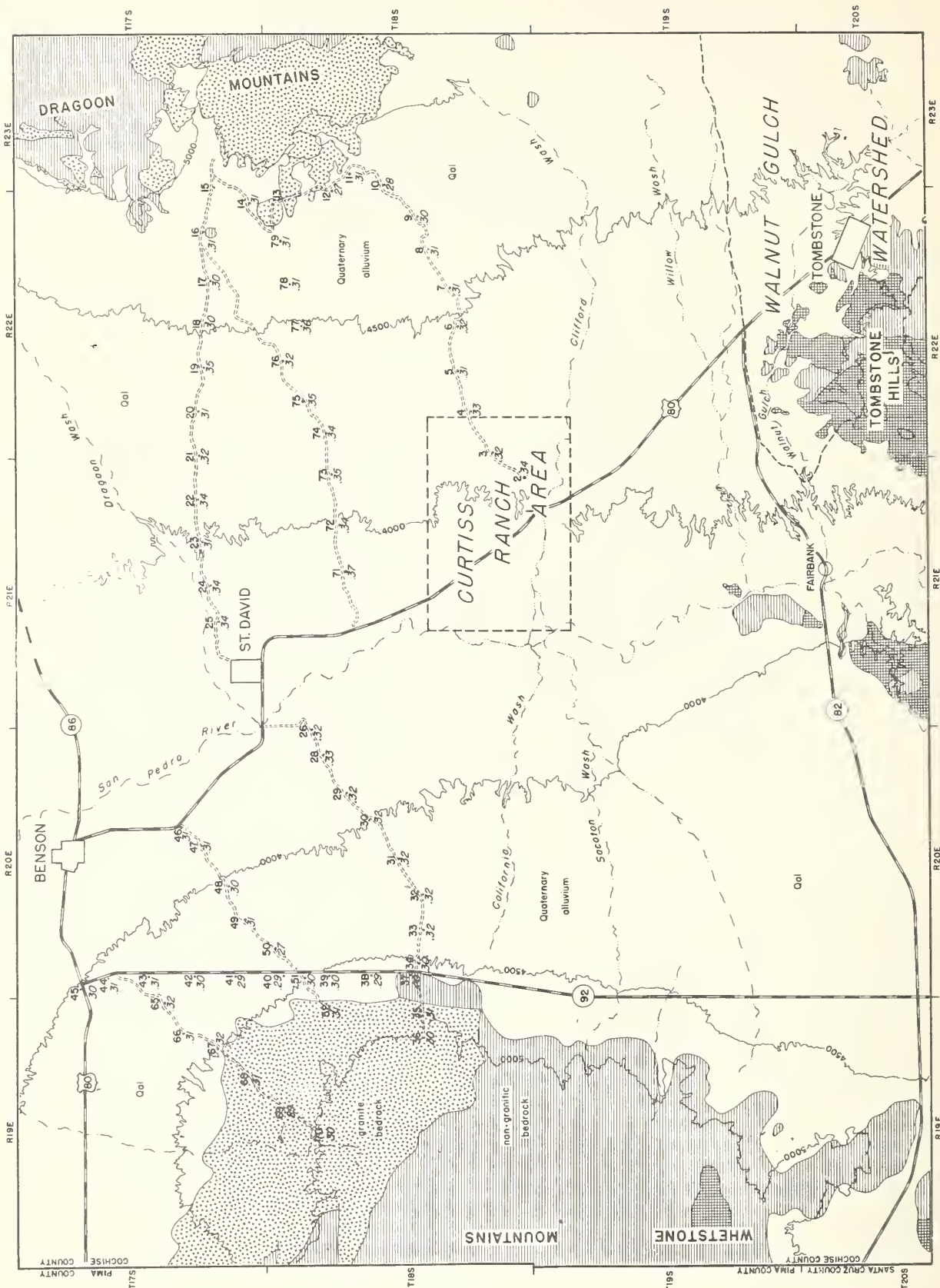
YOUNGER PLEISTOCENE ALLUVIAL GRAVELS

In the central part of the San Pedro Valley, Late Pleistocene fanglomerate and gravel alluvium unconformably overlie Early and Middle Pleistocene silts and clays, and form the surface deposits over most of the valley basin. Along a belt of varying width on each side of the present river channel, Late Pleistocene and Recent scouring has removed much of the older valley fill and the overlying gravel. This area, underlain by modern and somewhat older flood plain alluvium, corresponds to the Aravaipa Surface of Bryan.³ From the escarpment forming the margin of this lower level, a broad flat surface of very low relief and gentle slope extends upward to the bedrock outcrops of the two mountain fronts. This is the Whetstone Surface (2), best developed between Benson and St. David (fig. 1), from which the samples were obtained for this quartz abrasion study. The sand and gravel, from their origin at the base of the mountain fronts to their termination near the valley axis, overlie the older units of the valley fill. The

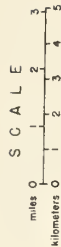
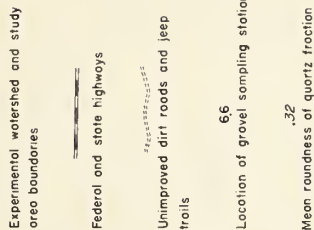
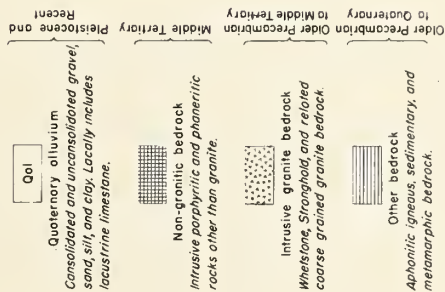
¹Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture in cooperation with the Arizona Agricultural Experiment Station.

²Located at Tucson, Ariz.

³Underscored numbers in parentheses refer to References at end of report.



EXPLANATION



Topography modified from USGS quadrangle maps of Benson, Si David, Tombstone, and Ft. Huachuca, original scale 1:62,500. Geology modified from Gilluly (1956) and Arizona Bureau of Mines Geologic Map of Cochise County, Arizona (1959), original scales 1:62,500 and 1:375,000, respectively.

Figure 1. --Index map of Benson-Tombstone region, Cochise County, Ariz., with generalized geology and location of sampling stations.

upper reaches of the gravels have been deposited on a partially exhumed bedrock apron often described as a pediment surface. Many remnant knobs of a dark-brown clay facies of the valley fill can be observed along U.S. Highway No. 80, covered by well-oxidized, medium-red-brown gravels of the Whetstone Surface. Stream reworking is apparent in some of these lower exposures of the gravels.

Exposures in the upper reaches of streams draining the San Pedro River Valley show less contrast between the valley fill and the upper gravels. Here the upper part of the valley fill is relatively coarse and tends toward a light red-brown color. At all exposures seen, however, the contact between valley fill and gravel alluvium was apparent. It is possible that nearer the two mountain ranges, where erosion has not yet exposed the uppermost basin fill and its contact with the overlying deposits, there may be evidence that the time interval between the two types is relatively short.

The alluvial gravels originating in the coarse granite sources of the northern Whetstone and Dragoon ranges show a medium red-brown coloration as a result of iron oxide staining. All sizes and types of rock and mineral constituents seem so affected. The alluvial material derived from the disintegration of granitic rocks, aside from size, is quite uniform in appearance and texture, and was chosen for the quartz abrasion study for this reason.

Laterally, the gravel alluvium varies in color and texture, reflecting the contribution of different source materials in the mountains. Locally, the red-brown color is masked in varying degrees by lime, generally more so near the Tombstone area. This color change in the alluvium, together with the compositional and textural changes, makes correlation more difficult near the complex area toward Tombstone.

At many localities a shallow soil with an "A" horizon is present on the surface of the gravel alluvium. The soil appears best developed where grass covers the surface, rather than the more usual creosotebush, whitethorn or other shrubs. This soil member is apparently related to the present soil-forming regimen, and its geologic age is probably recent.

The medium-red-brown soil, best developed where the gravel alluvium originates in granitic sources, has been described by several workers as a probable Sangamon paleosol developed on a glacial deposit of Illinoian age^{4 5}. In most localities, this phase of the soil profile is surficial, either because of removal of any preexisting "A" horizon or because a distinct "A" horizon was never developed. The assignment of third interglacial age (Sangamon) to the medium-red-brown soil is partially based on the presence of a higher, coarser boulder deposit overlying the fanglomerate that has been tentatively assigned to the fourth glacial age (Wisconsin). We believe, however, that the boulder zone and the gravels may be of equivalent age.

Boulder zones similar to those girdling the mountains in the Benson-Tombstone area have recently been described in the study of modern arroyo deposition in southeastern Arizona by Wertz⁶. In an extensive study of the spacial distribution of sediment in some 20 modern arroyo beds, Wertz found a recurring threefold division of sediment into a boulder phase, a mixed boulder and sand phase, and a sand phase. The relative width of each zone varied with local conditions, maturity of the mountains, and other factors; but the separation into the several phases was always evident. The boulder zone recognizable at many localities on the Whetstone Surface, or on other similar surfaces in this area, may be related to the initial boulder phase of primary deposition of a single gravel unit and may not represent a separate deposit of younger age.

The greater slope of these coarse deposits and their high angularity do not necessarily imply that they are younger than the alluvial gravels. The slope of the coarse deposits adjacent

⁴ Smith, D. G. Pleistocene geology and geomorphology of the San Pedro River Valley, Cochise Co., Arizona. Unpublished master's thesis, University of Arizona, 73 pages. 1963.

⁵ Melton, _____. Personal communication, 1962.

⁶ Wertz, J. B. Mechanism of erosion and deposition along channelways, Unpublished doctor's thesis, University of Arizona, 500 pages. 1962.

to the mountains is greater because the greatest mass of transported sediment is deposited immediately after the stream leaves the confines of the canyon walls.

The change in slope between the boulder-gravel complex adjacent to the mountains and the predominantly gravel deposits farther downslope is continuous. Nowhere was an abrupt change from a steeper angle to a shallower one observed; the change is always gradual.

The apparently greater angularity of the surficial boulders may in some cases be related to distance of transport. The presence of bedrock on the pediments before the mountain fronts suggests that many of the large, more angular boulders are derived from these outcrops and have not traveled as far as the rest of the material. Although the mountain divide is only a few miles from the mountain fronts in most places, the distance is still sufficient to cause observable rounding.

The coarse boulder deposits may, therefore, be related to the entire gravel-alluvium depositional sequence and not a separate or younger unit as has been considered. The change in surface slope, disparities in angularity, or other differences, can also be explained by variations in initial stream deposition, subsequent lag concentration, or presence of outcrops on the bedrock apron.

Evidence from sedimentary studies and from vertebrate and invertebrate paleontology indicates a second glacial age (Kansan) for most of the fine-grained units of the valley fill. It is possible that the transition into the coarse units near the top of the valley-fill sequence or into the uppermost erosion surface, or both, is related to the transition from glacio-pluvial Kansan time to Yarmouth interglacial time. The overlying gravel alluvium would then be of Illinoian glacial age at the oldest. In this case, the previously discussed boulder zone above the gravel alluvium could be of the same (Illinoian) age or younger. Another possibility is that the entire gravel alluvium, both boulder zone and typical gravels, is of younger (Wisconsin) age and that Illinoian-Sangamon deposits or erosion surfaces have not yet been recognized in the sequence.

LATE PLEISTOCENE OR RECENT RIVER TERRACE DEPOSITS

River terrace deposits, younger than the sequence so far discussed, can be observed at a number of localities in the central part of the San Pedro Valley. These rounded lag boulders and cobbles are much larger and darker than the underlying valley fill or gravel alluvium in all localities thus far observed. The darker color is due to "desert varnish" surface discoloration. The rock types include a high percentage of Paleozoic limestones, quartzites, Tertiary volcanics, shallow intrusives, and other local rock types.

This deposit was apparently left above the older sediments by former high stages of the San Pedro River, during latest Pleistocene or recent time. Although this younger unit is very likely related to the downcutting phase that established the escarpment along the inner margin of the exposed basin fill-alluvial fan complex, its precise age and extent will require further field study and geomorphic investigations.

At the Boquillas area, Smith³ recognized at least three river terraces distinct from the Tombstone and Whetstone Surfaces. Our field observations near Keller Ranch, Boquillas, and the surrounding area seem to agree with these findings. A traverse from the river past the Keller Ranch area westward toward the Whetstone Mountains reveals a series of broad, flat surfaces capped by river boulders and cobbles. This sequence probably just preceded the cutting and deposition of the lowest and youngest level described by Bryan (2)--the Aravaipa Surface.

FIELD SAMPLING

Sample collections in the field were restricted to the gravel alluvium of probable Illinoian age. Because of its wide distribution and the consistency of lithologic characteristics, this

stratigraphic unit was ideal for studies of roundness and sedimentary maturity. More than eighty 2-pound samples were collected from below the zones of weathering at points approximately 1 mile apart on the east and west sides of the San Pedro River Valley. See Index Map, figure 1.

LABORATORY METHODS OF DETERMINING ROUNDNESS

Roundness is defined by the sharpness of the edges and corners of a sedimentary particle and is independent of particle shape (10). The quality of roundness gives the geologist some idea of the distance the sediment was transported. The modal grain size is very generally indicative of the degree of tectonic activity.

Krumbein's visual comparison chart (4, 5) was used almost exclusively in this study for determining statistical roundness values, and was supplemented by Powers' classification (10). Krumbein's method of roundness determination is the more tedious of the two, but we believe it to be the more effective. His chart shows silhouettes of grains for nine roundness values in arithmetic progression from 0.1 to 0.9, with no descriptive maturity class given to any division. The value 0.1 indicates the most angular grains, and 0.9 indicates those that exhibit the best rounding. Although the original chart actually was derived from pebbles in the 16- to 32-mm. size range, Krumbein indicated that it can be applied to almost any size range by enlarging or reducing the images photographically.

The roundness studies reported in this paper were in the main confined to a 2-mm. size range (-1 phi), and were restricted to the study of quartz grains. The size of 2 mm. was selected for this study because it marks the border between sand and gravel (Wentworth classification). Hence, this study can also be related to the abrasive effects on coarse sand. The size range designated was obtained by separation on standard U.S. sieves, and the quartz grains were isolated visually. To assign values, each grain was individually held against the contrasting background of the chart, viewed in silhouette, and compared with the images. For example, if the grain was matched with the third rectangle in the upper row of the chart, a value of 0.3 was assigned. No fewer than 50 quartz grains were counted from each field collection station, and the average roundness value was then obtained.

Powers' values (10) are adequate for roundness studies, but do not give as thorough a breakdown as do Krumbein's methods (4, 5). The inclusion of descriptive classes makes Powers' chart applicable to maturity studies; therefore, it was used to assign class values, such as "very angular to subangular."

ROUNDNESS STUDIES

Information From Other Studies

The sediments of greatest interest to the geologist are those that reveal information concerning depositional environments, source and distance of transport, and rates of wear on sediments during transport. Each sediment is responsive to a definite set of environmental conditions, and the deposit reflects those conditions to a limited degree. Since environmental studies depend largely on interpretations made from sedimentary properties existing in a stratigraphic unit, they must, when feasible, be supplemented by other evidences, such as fossils.

The present investigation was restricted to determining the relation of roundness of sediments to their rate of abrasion and the distance transported. There are, of course, other factors than distance determining the rate of wear of sediments. Size and mineral resistance are the characteristics of the sediment that affect its wear; factors influencing abrasion are force of action, duration, and distance traveled.

There is a correlation between roundness and size, the larger gravel or sand grains being more readily rounded than the smaller ones. The size-roundness relationship must, therefore, change constantly as the gravel is abraded, so that reduction in size will be accompanied by a decreased rate of wear. To present evidence of a single characteristic, it was necessary to avoid the influencing factors of size and mineral type. Therefore, the study was restricted to one size range, 2 mm., and a single mineral type, quartz.

In many gravel deposits, roundness of some grains is intensified by solution. This is a factor acting on calcareous gravels and others of high solubility. Since this study was restricted to quartz, solubility was negligible and did not distort the evidence of rounding activity.

In general, mean sediment size of alluvial material decreases with distance of transport. Such a depositional phenomenon results primarily from a decreasing competence of the stream, coinciding with gradient decreases (9). Although much of the size decrease can be attributed to selective transport, it is also the result of abrasive and other wear factors. Settling velocity is not particularly dependent on the roundness of the gravel particles, and changes in the conditions of transport may not be evident in rounding except, perhaps, in the rates of wear.

Roundness is extremely sensitive to abrasion, and angular particles change rapidly in their degree of roundness during transport. In its youthful stage, a clastic particle is characterized by extreme angularity, but during transport this property is quickly modified in the first few miles of transport. Thereafter, although particle wear continues, it is at a much slower rate. It also seems clear that, as the sediment goes through various cycles of erosion and deposition, the size will be continuously reduced until it ultimately reaches a minimum grain. Several samples selected at random from the 4-mm. size range were analyzed, and in all cases they were found to be better rounded for particular distances traveled than their correspondents in the 2-mm. size range.

The force of abrasive action must have been of a high-energy character, since this is a widespread, coarse deposit. Also, distance transported in this case was not great, since the study was restricted to the collection of sediment that had been transported only from 1 to 10 miles. See Index Map, figure 1.

Results From Roundness Studies

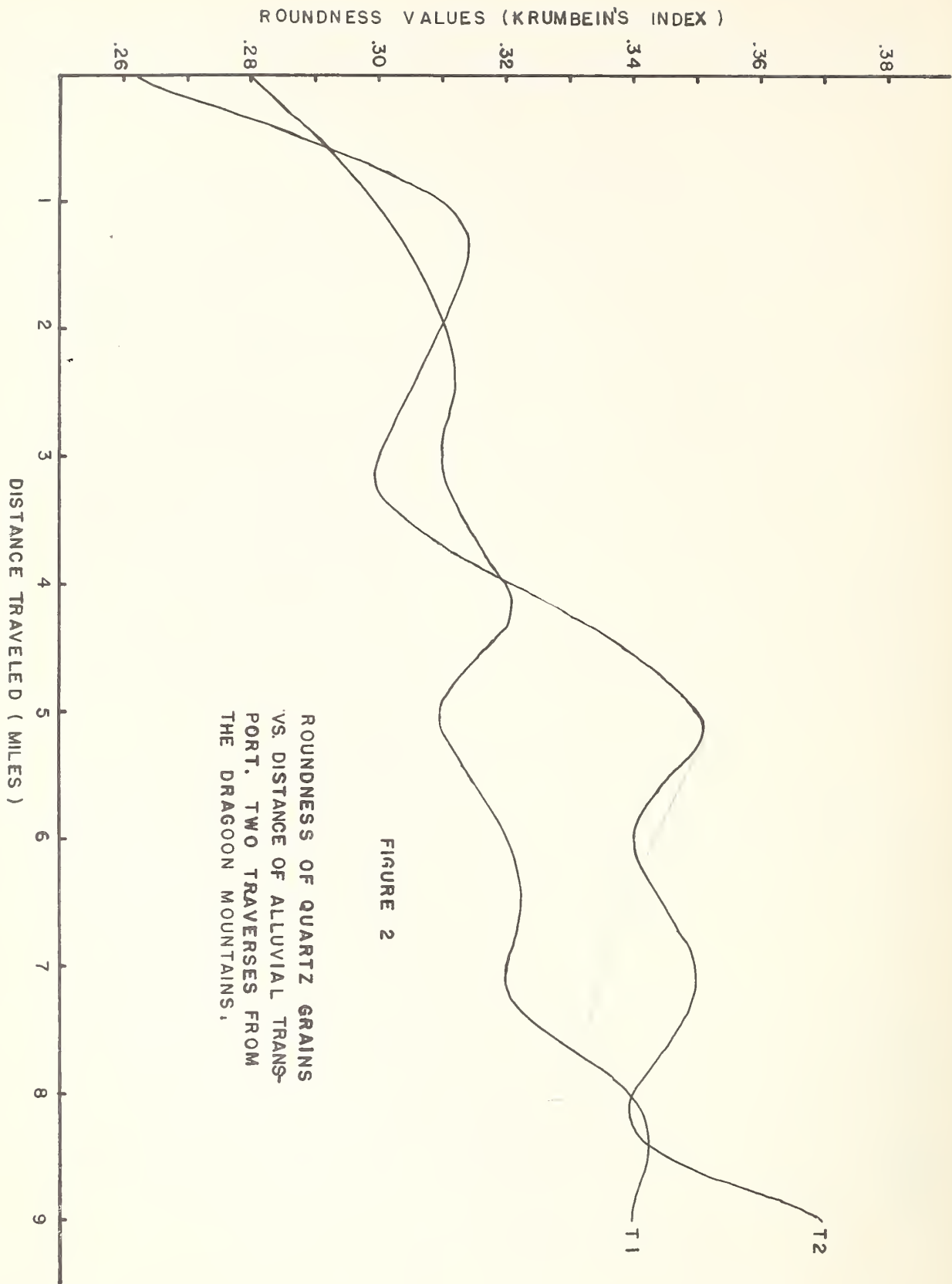
Figures 2 and 3 show an increasingly slow but definite rounding of the quartz grains with an increased transport distance from the source area. Because of the relatively short traverse length and the durability of quartz, the total degree of rounding is not great. The grains analyzed from the east side of the San Pedro Valley show a slightly greater abrasion effect than do those from the west side. The eastern sediments were transported a greater distance, and were deposited on a wider flood-plain area, where they were subjected to a longer period of abrasive action.

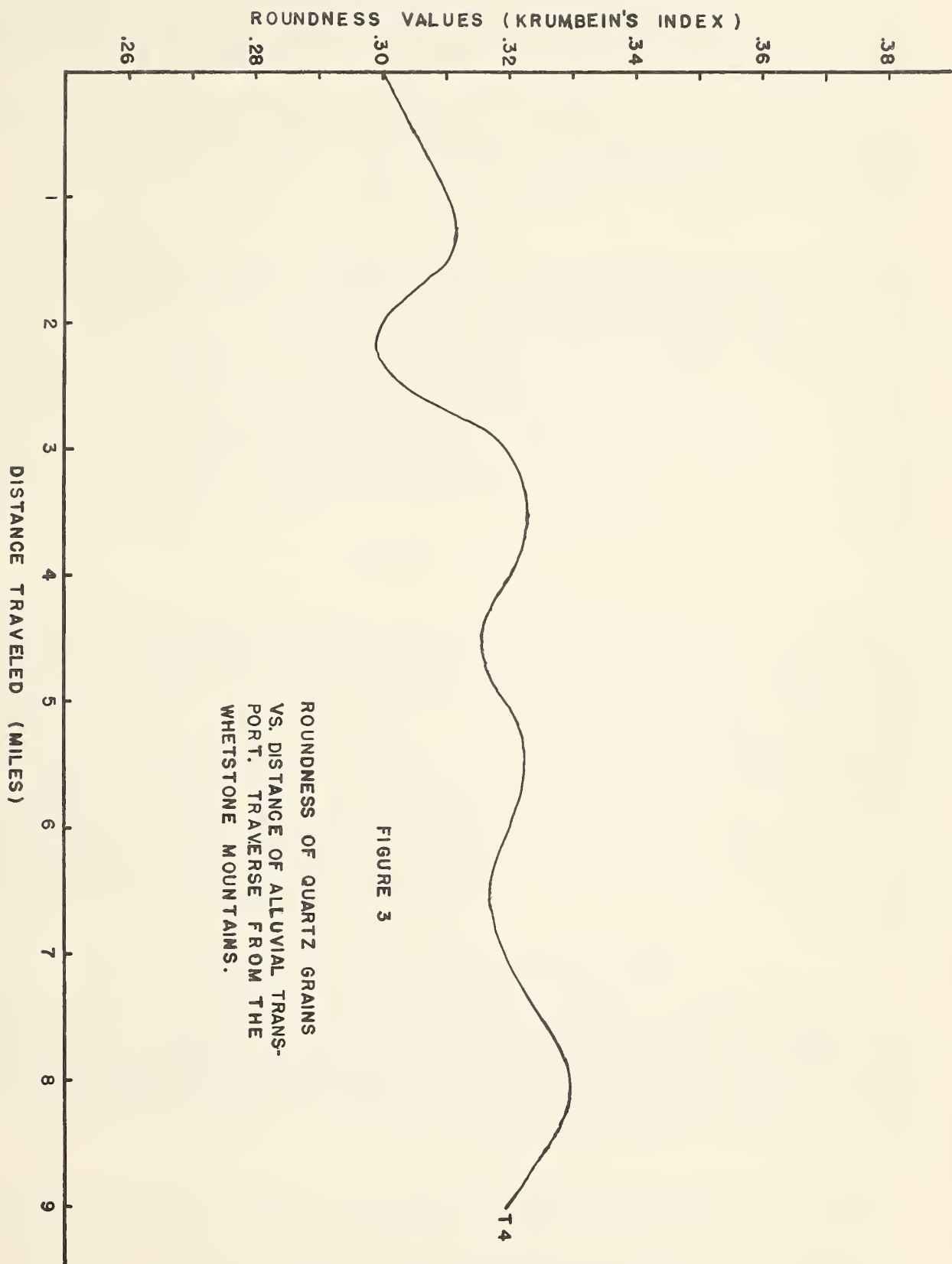
Most of the abrasive wear occurred during the first 1 or 2 miles. After the initial stages of rounding, the process was much slower. None of the traverse collections showed an average roundness, by Krumbein's classification, much greater than 0.3. Only those quartz grains deposited well out on the flood plain near the San Pedro River reached the category of 0.4. By application of Powers' criteria the quartz grains closest to the source were shown to be very angular to angular, and those farthest from the source to be angular to subangular.

We believe that source areas can be determined through detailed roundness studies and by application of isopleth maps. Isopleth contours drawn through equal values on the base map would show progressive rounding with increased distances from the source. In this study the Dragoon and Whetstone Mountains are clearly indicated as the granitic source areas.

SEDIMENTARY MATURITY STUDIES

Maturity is the measure of the approach of a clastic sediment particle to a stable end product (8) resulting from the formative processes operating on it. Sedimentary maturity is a combined





record of the duration of the operative processes and the intensity of action. During transportation, weak sediments will be quickly reduced in size and carried away as silt and clay. Coarser particles are reduced, after long or vigorous transport, to a residue of some durable material such as quartz.

The relative relief of the source area (the mountainous area supplying the sediments) is an important factor in determining duration and intensity of erosive action and sediment deposition. High relief promotes rapid erosion, and low relief tends to retard the erosive processes.

Compositional Maturity

Compositional maturity may be expressed in mineralogic or chemical terms, and will approach a relatively stable end product of high quartz concentrations. Since quartz, the primary silicate, is of plutonic origin, it would be predominately associated with feldspar during its immature stages. A measure of maturity may then be expressed by the disappearance of the less stable feldspar. For this reason, a quartz-feldspar ratio count is important in determining the maturity of a sedimentary deposit, provided the source area was not originally low in feldspar. The major source areas for the gravel alluvium, the Dagoon and Whetstone Mountains, both contain an abundance of feldspar. Quartz-feldspar ratios determined on samples collected at the foot of the mountains show a slightly greater preponderance of feldspar. Counts made farther out in the valley show only a small change from the original ratio, with the quartz becoming slightly predominant. In comparison with samples approximate to the mountains, those most remote show some measure of compositional maturity, but the deposit is still largely immature.

Textural Maturity

Textural maturity is expressed in terms of the clay content of a coarse deposit, the degree of sedimentary sorting, and the roundness of the grains, particularly quartz (3). Initially, a gravel deposit is high in interstitial clay, poorly sorted by size, and composed of angular grains. In its mature stage, it displays very little clay (less than 5 percent), is well sorted, and contains well-rounded quartz. Clay is removed rather rapidly, but sorting and rounding occur only after prolonged and vigorous transport.

Laboratory analysis shows that the clay content of the gravel alluvium is slightly over 10 percent near the mountains, with very little change farther out in the valley. This contrasts with the underlying valley fill of the Middle Pleistocene epoch, which in many cases exhibits a high percentage of clay minerals. These clays may have resulted from the chemical breakdown of feldspar prior to deposition of the gravel alluvium. Since sorting of the gravel alluvium is poor and the grains generally do not go beyond the angular stage, the deposit is classified as texturally immature.

Conclusions From the Maturity Studies

Sufficient evidence has been presented to identify the immature sedimentary nature of the gravel alluvium. The implications are: (1) Rapid erosion in the source area, and (2) rapid transportation and deposition. If the source area had been of low relief, the gravel yield would have been small and the sediments would be composed of chemically inert materials. Only an area of high relief undergoing rapid erosion could produce so widespread a deposit of coarse, immature gravel as that described in this paper.

IMPLICATIONS OF TECTONIC UPLIFT IN LATE PLEISTOCENE TIMES

Tectonic uplift is indicated by the study of the sediments described in this paper. However, evidence is far from complete and is only alluded to at this stage of research.

It is stated above that high relief in the source area promotes relatively rapid erosion, transportation, and deposition. In contrast with the Late Pleistocene deposit, the older valley fill of Middle Pleistocene (Kansan) is predominately a fine-grained silt and clay. The general absence of coarse material indicates that the rate of erosion in the source area was slow, and implies deposition in a low-energy environment. This suggests that the source area must have been at an elevation somewhat lower than at present.

The overlying gravel alluvium stands in contrast to the older valley fill, and has been described as a widespread blanket deposit resulting from high-energy environmental situations. The deposits increase in coarseness ascending the stratigraphic column, and in many cases, are composed of coarse cobble conglomerates. The implications are increased relief of the source areas, accompanied by an increase in rates of erosion.

Changing climatic conditions undoubtedly played a major role in the sedimentary results, but evidence of their influence is not conclusive. Moist conditions existing in Kansan time undoubtedly had much to do with the abundance of clay in the valley fill. The converse is not necessarily true, however, and the scarcity of clay in the later Illinoian time does not of itself imply that conditions were drier. If, during the latter time, relief was high in the source area, then the rates of erosion, transportation, and deposition would have been rapid enough to avoid chemical breakdown of the complex silicates even under wet conditions.

The Walnut Gulch watershed area, as well as much of the rest of San Pedro Valley, is presently undergoing a general phase of erosion. The hypothesis of Late Pleistocene regional uplift explains why these areas are currently in a degrading stage.

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